Leaching and Recovery of ^{15}N in Dryland and Irrigated Cropping Systems

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Abstract

Laird-lentil and Neepawa-wheat were grown under irrigation in 1987 at the experimental Irrigation Farm at Outlook under three levels of N: 10, 50 and 100 kg of NH_4NO_3, double labelled with ^{15}N. A similar experiment was conducted at the same site under dryland conditions in close vicinity to the experiment under irrigation. Soil samples to a depth of 120 cm from the plots receiving 10, 50, and 100 kg N/ha were taken at 44, 63, and 101 days after planting, divided into 0-15, 15-30, 30-60, 60-90, and 90-120 cm sections, and analyzed for total N, available N, and atom % ^{15}N.

Total recovery of N-fertilizer in the soil decreased through time, irrespective of crop or water regime. While almost no leaching below 15 cm occurred under dryland-lentil, N leached into the 15-30 cm soil zone under dryland-wheat after rain during the last part of the growing season. During that period N accumulation still occurred in lentil but had ceased in wheat.

At final harvest and under irrigated conditions, 9% of N applied (100 kg N/ha) had leached below 30 cm when the soil was cropped with lentil and 7% when cropped with wheat.

Regardless of the amount of N applied, moisture regime, or crop grown, a minimum concentration of available soil-N of around 8 ppm (150 kg N/ha to a depth of 120 cm) was always present. It appeared that in this study mineral soil-N became only available for plant uptake when the mineral N concentration exceeded 8 ppm.

The amount of total available soil N in the form of NH_4^+ remained constant in the dryland soil. However, under irrigation there was a sharp increase in the amount of NH_4^+. Lack of O_2 in the water saturated top soil reduced nitrification activity and NH_4^+ levels increased.

On average, total fertilizer-N recovered in plant and soil was 50%, regardless of crop or water regime, and remained fairly constant throughout the growing season. However, percent N-fertilizer recovered in the soil decreased and the percent fertilizer-N recovered in the plant increased over time.

Possible N-losses can be attributed to denitrification, nitrification, ammonia volatilization, and/or NH_4^+ fixation. The percentage of ^{15}N-fertilizer recovery found in this study agrees with other published data from Saskatchewan.

INTRODUCTION

Leaching of applied N-fertilizer has created potential pollution problems, in particular in those areas were groundwater is used for drinking. Increased NO_3^- levels in groundwater of up to 50 ppm have been found and it is assumed that most of this originated from excess fertilizer-N applications and from the oxidation of organic matter. Improved management techniques will be required to reduce soil-water pollution and to increase fertilizer-N use efficiency by crops.

It is known that under controlled environments plants are able to take up all available N present in a nutrient solution. Under field conditions, however, nitrate can leach below the rooting zone, even when the plants are stressed for N, because the roots are not able to absorb all NO_3^- at low concentration (Viets, 1975).

The recovery of applied fertilizer has varied widely from close to 100% (Carter et al., 1967; Power and Legg, 1984) to 35% (Wagner, 1965). The large differences in the percent N recovery between studies may be because of (i) differences in soil types, (ii) the use of steel cylinders in which the ^{15}N-labelled fertilizer was placed and could have reduced run-off or vertical leaching, (iii) the form in which the fertilizer-N was applied, (iv) the choice of the crop grown, and (v) the methodology used for measuring the recovery of fertilizer.

The purpose of this experiment was to assess the extent of leaching as affected by the amount of applied fertilizer-N and irrigation, to determine the effect of crop on leaching, to determine under field conditions the level of mineral soil N at which N becomes unavailable, and to calculate the ^{15}N-fertilizer recovery in plant and soil.

MATERIALS AND METHODS

The experimental site was located at the Experimental Irrigation Development Centre at Outlook, Saskatchewan. Two experiments were conducted simultaneously; one under centre pivot irrigation, the other under dryland conditions. Additional details of the experiment and soil characteristics are reported in a related chapter entitled *"Yield, ^{15}N-uptake, and fertilizer use efficiency of irrigated and dryland wheat and lentil throughout the growing season under various levels of nitrogen"* by C. van Kessel and N.J. Livingston and published elsewhere in the Proceedings.

Nitrogen was applied at three levels: 10, 50, and 100 kg/ha in the form of NH_4NO_3. ^{15}N-microplots, 1.05 by 2.85 m for each individual harvest plot or 1.05 by 20.0 m for each subplot, were installed in the middle of each subplot. Values for atom % ^{15}N excess of the applied double ^{15}N-labelled NH_4NO_3 were 4.6337, 0.9267, and 0.4634 for the 10, 50, and 100 kg N/ha, respectively. Treatments were laid out in a split-plot design, with main plots arranged in a randomized complete block. Treatments were replicated four times with lentil or wheat as mainplot and N-level as subplot treatment. Subplots measured 20 by 3.7 m. Irrigated plots were located under a centre pivot system, the non-irrigated plots were just outside reach of the centre pivot.

Soil samples were taken 44, 63, and 101 days after planting. Two soil cores, 7.5 cm in diameter, were taken from each subplot to a depth of 120 cm, separated into 0-15, 15-30, 30-45, 60-90 and 90-120 cm sections, thoroughly mixed, and subsampled. Soil samples were frozen until analysis. Total N, including nitrate and nitrite, was determined by micro-Kjeldahl analysis (Bremner and Mulvaney, 1982). Inorganic soil-N, NH_4^+ and NO_3^-, was determined by extracting 100 g of soil with 2 M KCl and steam distilling the extract after adding a MgO-Devarda alloy mixture (Keeney and Nelson, 1982). NO_3^- and NH_4^+ in the KCl soil extract were separated by distilling the extract first without Devarda alloy for the determination of the NH_4^+. A second steam distillation of the same extract was carried out with Devarda alloy and mineral NO_3^- determined.

^{15}N analysis was carried out by conversion of NH_4^+ to N_2 by LiBrOH (Ross and Martin, 1970; Porter and O'Deen, 1977) and the $^{15}N/^{14}N$ ratio determined by a VG Micromass 602E isotope ratio mass spectrometer.

Calculations from ^{15}N data were as follows:

$$\text{\% Ndffs (\% N derived from fertilizer in soil)} = \frac{\text{atom \% } ^{15}\text{N excess (soil)}}{\text{atom \% } ^{15}\text{N excess (fertilizer)}} \times 100 \qquad [1]$$

$$\text{kg Ndffs (kg N derived from fertilizer in soil)} = \text{(\% Ndffs x total N in soil)} \qquad [2]$$

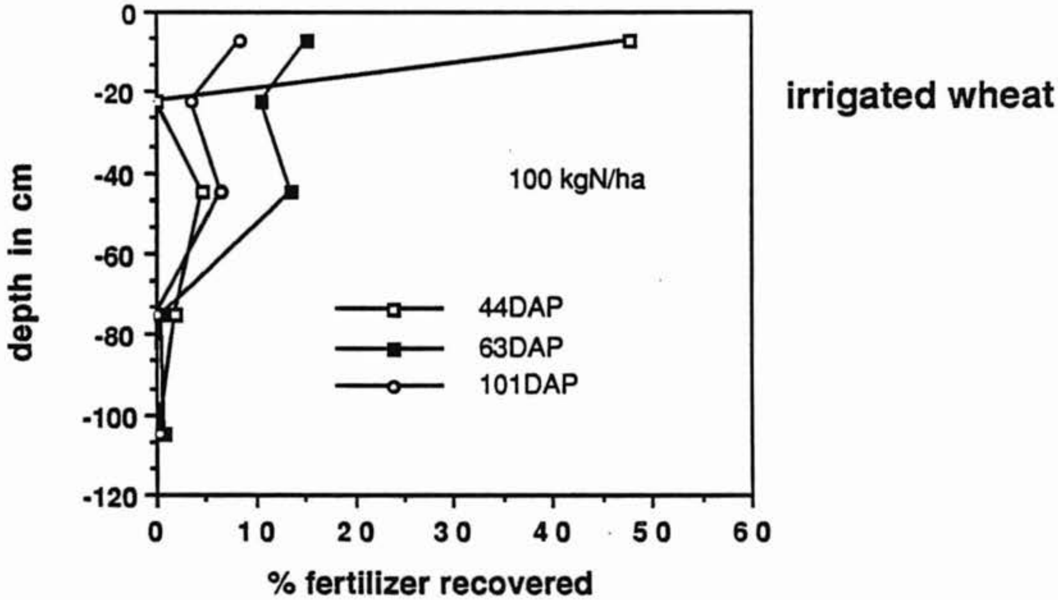
$$\text{\% FUE in soil (\% fertilizer use efficiency in soil)} = \frac{\text{kg Ndffs}}{\text{kg N fertilizer applied}} \times 100 \qquad [3]$$

$$\text{Total \% FUE} = \text{\% FUE in soil} + \text{\% FUE in plant} \qquad [4]$$

The ^{15}N natural abundance of the soil N pool was 0.36925 atom % and this value was used for calculating the atom % ^{15}N excess of the soil. If appropriate, irrigated and dryland crops were compared using the t-test comparison. LSD (<0.05) between means were calculated if F values were significant.

RESULTS AND DISCUSSION

Leaching of N in irrigated soil was low at 44 DAP, increased at 63 DAP but decreased again toward the end of the growing season (Fig. 1). At 44 DAP most of the fertilizer was recovered from the top 15 cm, and the end of the growing season 9% and 7% of the 100 kg N/ha was leached below the 30 cm soil surface when applied to wheat and lentil, respectively. The lower fertilizer-N recovery in the soil at 101 DAP as compared with 44 DAP or 63 DAP was caused by fertilizer N uptake by the crops and possible N losses caused by N_2O production through denitrification and/or nitrification. Some leaching below the 120 cm depth may have occurred but this amount was insignificant. At the highest fertilizer rates more leaching of N occurred in a soil cropped with lentil, than with wheat and may have been caused by the difference in the N uptake curve between the two crop (*see also related chapter*). N-leaching can largely be reduced through crop N-uptake. Wheat accumulated most of its N during the first 6 to 8 weeks after planting whereas the N-



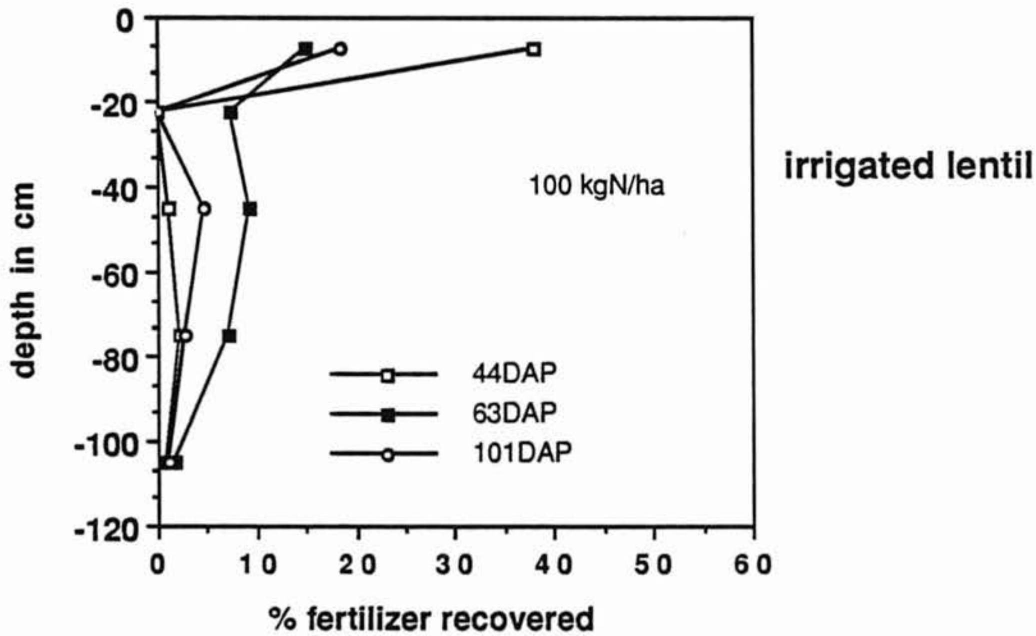


Figure 1. Movement of N under irrigated wheat and lentil.

uptake for lentil occurred in the later part of the growing season. At that time, some of the fertilizer-N under irrigated lentil had leached into 30 to 90 cm soil zone.

Less than 10% of the 100 kg N/ha applied fertilizer leached below the 30 cm depth in the growing season. The amount of the residual fertilizer-N in the top 30 cm that might leach into lower depths during the second growing season is yet to be determined. Furthermore it is not known how much of the fertilizer-N already found below the 30 cm depth might leach further down the soil profile during subsequent growing seasons.

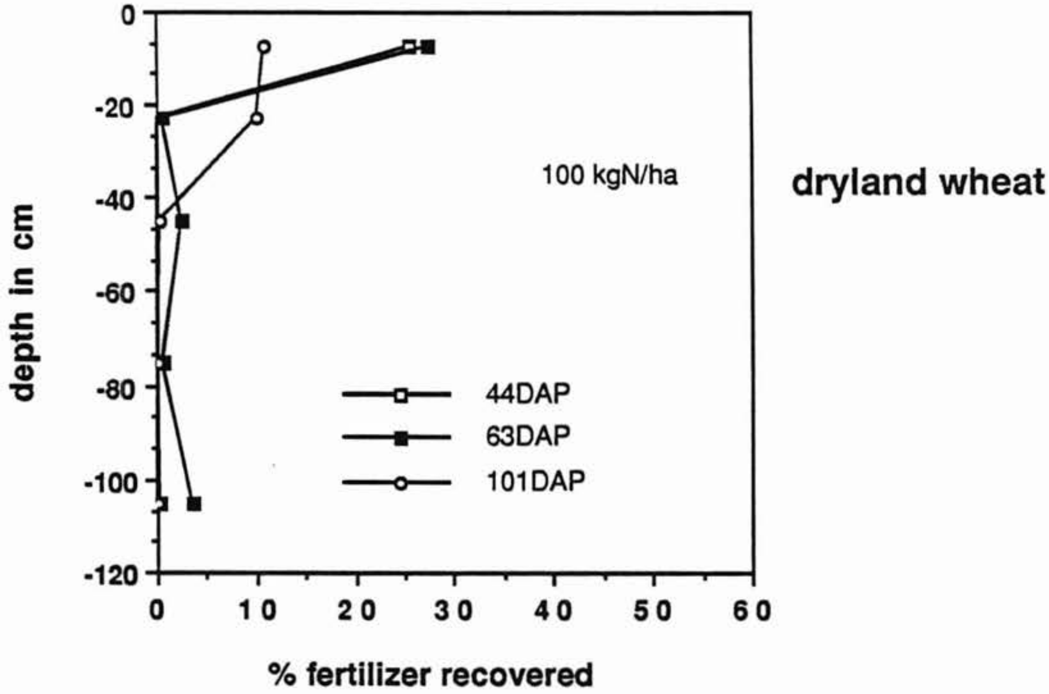
Under dryland conditions no leaching of the spring applied 100 kg N/ha occurred below the 15 cm depth under lentil however some of the applied N appeared in the 15-30 cm depth at final harvest under wheat (Fig. 2). As with irrigated wheat and lentil, dryland wheat accumulated most of its N early in the growing season whereas lentil accumulated a major portion of its N during the second part of the growing period. Most of the rainfall occurred in the latter part of the growing season at which time the fertilizer-N in soil under wheat became more susceptible to leaching because of little or no plant N uptake. A somewhat similar increase in N leaching into the 15-30 cm depth at final harvest was also observed when 50 kg N/ha applied (Table 1). No leaching occurred when only 10 kg N/ha was applied.

The amount of total ^{15}N recovery in the soil in the 0-120 cm layer was independent of the amount of N applied or irrigation (Table 1). The total recovery of ^{15}N in the soil decreased over time but the decrease was similar for all three levels of fertilizer-N tested.

The total amount of mineral N was independent of the crop but dependent of the amount of N applied (Table 2). Under irrigated conditions higher N application caused higher extractable mineral N at 44 DAP and remained higher throughout the growing season, though not significantly at the 63 DAP sampling period. The increase of mineral N at the end of the growing season under wheat was most likely caused by the net N-mineralization occurring at the end of the season without the concurrent N uptake by wheat. During that period wheat had ceased to accumulate N and a build-up of mineral N might have occurred. This is in contrast with irrigated lentil with showed increased total N accumulation at the end of the growing season. The mineral N in a soil cropped with lentil remained fairly constant throughout the growing season.

Under dryland conditions, the mineral N pool was independent of crop and the amount of applied fertilizer-N but decreased during the growing season. At 44 DAP, significantly higher amounts of mineral N were found under dryland both in wheat and lentil than under irrigated conditions. This can be explained by the degree of N accumulation between the dryland and irrigated crops. Irrigation increased soil-N uptake by lentil and wheat by almost 100% as compared with dryland conditions. This caused a higher depletion of the mineral N pool in irrigated than in dryland soils during the early stages of the growth period. At the end of the growing season the net N-mineralization in irrigated soils increased. This did not occur in dryland soil and a significantly higher extractable mineral N was found in irrigated soil than in dryland soil under wheat. This in contrast with soil under dryland and irrigated lentil where lentil took up N until the end of the growing season and no difference in mineral N between irrigated and dryland soil was found.

The minimum concentration of available N, NH_4^+ and NO_3^-, under irrigated wheat and lentil that had received 10 kg N/ha was around 8 ppm and remained almost constant with soil depth (Fig. 3). This translates into an average of 60 kg mineral N/ha in the 0-60 cm depth or to 120 kg N/ha in the 0-120 cm depth. Wheat grown under 10 kg N/ha was N stressed (*see related chapter*) and showed significantly lower total N accumulation than



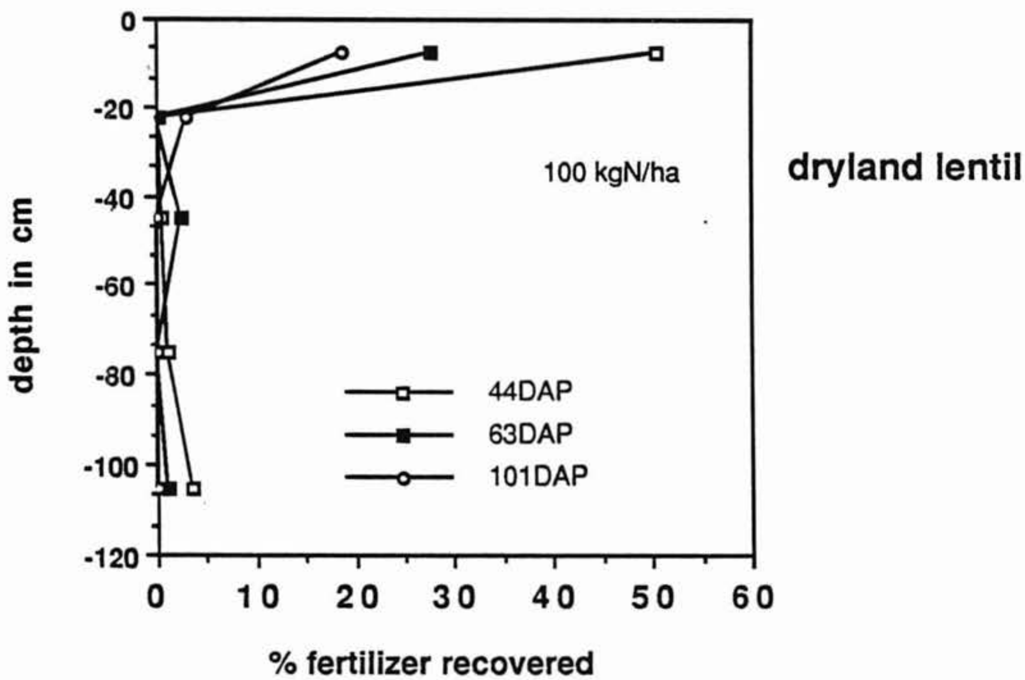


Figure 2. Movement of N under dryland wheat and lentil.

Table 1. Percent fertilizer-N recovered in soils as affected by crop and irrigation.

Days after planting	Crop	N rate	Irrigated						Dryland					
		kg/ha	0-15	15-30	30-60	60-90	90-120	0-120	0-15	15-30	30-60	60-90	90-	120
			cm											
			% FUE											
44	Wheat	10	27.3	1.5	1.8	0.9	0.3	31.8	27.1	1.1	3.5	0.0	2	.9
		50	18.5	9.2	1.9	1.0	0.3	30.9	32.2	0.0	4.2	1.3	9	.9
		100	47.9	0.0	4.5	1.8	0.2	54.4	25.5	0.0	0.0	0.0	0	.9
63		10	25.2	2.7	9.7	0.8	0.2	38.6	15.3	0.5	4.3	1.2	1	.0
		50	11.8	6.5	9.3	1.3	1.1	30.0	27.1	1.0	3.5	0.5	6	.2
		100	15.3	10.7	13.5	0.5	0.9	40.9	22.9	0.0	0.9	0.0	3	.3
101		10	12.2	0.0	1.1	0.1	0.3	13.7	22.9	0.0	0.9	0.0	0	.8
		50	9.5	0.1	4.7	0.1	0.4	14.8	22.5	2.6	0.0	0.0	0	.1
		100	8.3	3.5	6.5	0.0	0.2	18.5	10.9	10.0	0.2	0.0	0	.1
44	Lentil	10	22.3	2.2	7.4	3.1	0.5	35.5	29.4	0.0	0.9	0.1	2	.6
		50	39.9	2.7	2.0	1.6	0.9	47.1	58.2	0.1	2.1	0.8	1	.1
		100	38.1	0.0	1.2	2.1	0.8	42.2	50.6	0.2	0.6	1.2	3	.0
63		10	17.2	4.8	4.9	2.5	1.3	30.7	29.8	0.7	3.5	0.7	3	.1
		50	20.4	4.4	10.4	3.4	2.8	41.4	38.8	0.3	2.7	1.8	2	.4
		100	14.2	7.2	9.3	7.1	1.6	39.4	27.6	0.1	2.4	0.1	1	.4
101		10	14.2	0.2	2.8	0.0	0.6	17.8	17.9	0.4	0.0	0.0	1	.3
		50	17.5	1.1	2.3	0.3	2.7	23.9	17.3	0.5	0.2	0.0	0	.0
		100	18.5	0.1	4.7	2.7	1.2	27.2	18.8	3.0	0.0	0.0	0	.8
	LSD (<0.05)	Crop						NS						NS
		N						NS						NS
	LSD (<0.05)	I-D/W†						NS						
		I-D/L‡						NS						

Table 2. Total mineral N in irrigated and dryland soil as affected by crop, moisture and N application.

Crop	N rate kg/ha	44 days after planting (kg N/ha)		63 days after planting (kg N/ha)		101 days after planting (kg N/ha)	
		Total (cm)					
		0-60	0-120	0-60	0-120	0-60	0-120
		Irrigated					
Wheat	10	47	86	41	86	57	111
	50	50	106	40	96	57	111
	100	76	145	65	126	100	166
Lentil	10	41	101	49	108	51	101
	50	63	126	52	117	49	109
	100	67	129	67	130	53	120
LSD (<0.05)	Crop	NS	NS	NS	NS	NS	NS
LSD (<0.05)	N	18	28	NS	NS	15	27
		Dryland					
Wheat	10	60	171	58	152	38	110
	50	62	160	44	134	32	76
	100	116	204	59	156	75	135
Lentil	10	76	182	54	127	51	123
	50	82	205	92	184	46	122
	100	85	196	72	179	46	130
LSD (<0.05)	Crop	NS	NS	NS	NS	NS	NS
LSD (<0.05)	N	NS	NS	NS	NS	NS	NS
LSD (<0.05)	I-D/W†	28	37	NS	27	26	NS
LSD (<0.05)	I-D/L‡	14	27	NS	43	NS	NS

†Wheat (Irrigated vs. Dry)
‡Lentil (Irrigated vs. Dry)

wheat fertilized with 100 kg N/ha. Plants can be grown hydroponically under a constant N concentration of 8 ppm and the roots are able to almost completely deplete the available N in such a solution. Wheat grown under field conditions is not capable of absorbing NO_3^- and NH_4^+ as efficiently as that grown in a solution culture. This is consistent with the work of Viets (1975) who stated that some leaching of NO_3^- in soils will still occur even at low concentrations due to this inability of the roots to absorb NO_3^- at low concentrations.

Mineral N under irrigated wheat and lentil

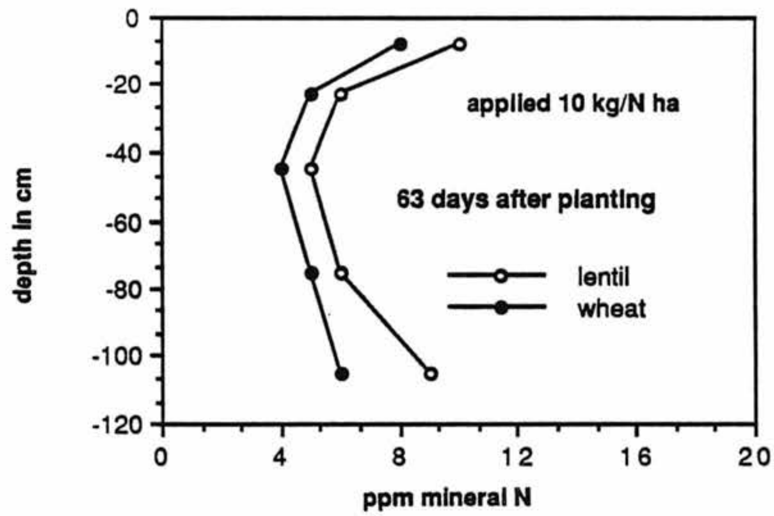


Figure 3. Mineral N under irrigated wheat and lentil.

Total mineral N is the sum of NH_4^+ and NO_3^-. The level of NH_4^+ in dryland soil fertilized with 100 kg N/ha and cropped to wheat, remained constant throughout the growing season and measured 33 kg NH_4^+-N/ha in the top 60 cm layer (Table 3). Total mineral NO_3^-N in the same dryland soil decreased from 101 kg/ha at 44 DAP to 40 kg/ha in the top 60 cm at final harvest. NH_4^+-N in irrigated soil, however, more than doubled at the end of the growing season and increased from 36 to 79 kg NH_4^+-N/ha or 82% of the total mineral N pool was in the form of NH_4^+. This sharp increase in NH_4^+ in irrigated soil can be explained by the waterlogged conditions found at the end of the growing season. Mineralization was occurring but the NH_4^+ formed during this process was not nitrified to NO_3^-. Nitrification is O_2 sensitive and lower O_2 concentrations in the soil reduces the process considerably (Amer and Bartholomew, 1951).

Total fertilizer-N recovery in plant and soil remained fairly constant throughout the growing season and was largely independent of the amount of N applied, crop or moisture regime (Table 4). The overall mean of the percent of fertilizer-N recovered of all treatments was 50%. This indicates that 50% of the applied N could not be accounted for and was lost from the system or had been fixed as NH_4^+ on clay particles and would not have been recovered with the method used for total N determinations. Similar N-losses in Saskatchewan have been reported by Carter and Rennie (1985) who found that between 7.2 and 53.5% of the applied N was unaccounted for. The study was conducted at various locations and under different tillage practices. N-losses were attributed mainly to NH_3-volatilization of the applied urea.

Possible N-losses in this study can be attributed to N_2O production during nitrification and denitrification, NH_3 volatilization from the crop (Parton et al., 1988), and through ^{15}N-NH_4^+ fixation by the clay minerals.

Table 3. Mineral N (NH_4^+ and NO_3^-) under wheat as affected by moisture.

Days after planting	Crop	Treatment	kg N/ha									
			0-60 cm					0-120 cm				
			NH_4^+	NO_3^-	Total	% NH_4^+	% NO_3^-	NH_4^+	NO_3^-	Total	% NH_4^+	% NO_3^-
44	Wheat	Dryland	33	101	135	26	74	61	135	196	32	68
		Irrigated	36	45	81	47	53	63	63	126	50	50
	LSD (<0.05)	D/I†	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
101	Wheat	Dryland	33	40	73	45	55	56	53	109	52	48
		Irrigated	79	18	96	82	18	105	38	143	74	26
	LSD (<0.05)	D/I	25	NS	14	27	27	33	NS	22	NS	NS

†Dryland/Irrigated

Table 4. Percent fertilizer recovered in soil and crop.

Crop	N rate kg/ha	Soil			Plant			Total		
		Days after planting								
		44	63	101	44	63	101	44	63	101
		Irrigated								
Wheat	10	31.8	38.6	13.7	16.6	28.1	32.1	48.4	66.7	45.8
	50	30.8	30.0	14.8	12.9	22.8	28.1	43.7	52.8	42.9
	100	54.4	41.1	18.5	11.8	25.6	36.4	66.2	66.6	54.9
Lentil	10	35.3	30.6	17.9	8.4	12.3	12.1	43.7	42.9	30.0
	50	47.0	41.5	23.9	5.9	18.4	13.5	52.9	59.8	37.5
	100	42.2	40.2	27.2	4.3	17.6	19.4	46.5	57.7	46.5
LSD (<0.05)	Crop	NS	NS	NS	7.3	NS	10.5	NS	NS	9.8
	N	NS	NS	NS	2.9	NS	NS	NS	NS	NS
		Dryland								
Wheat	10	34.0	23.0	23.8	13.7	14.0	14.5	47.7	37.0	38.2
	50	46.9	38.2	25.1	10.8	21.8	21.7	57.8	60.0	46.8
	100	26.0	34.6	21.2	9.5	15.0	22.2	35.5	49.6	43.4
Lentil	10	32.7	38.2	19.3	5.4	17.2	21.1	38.1	55.4	40.5
	50	63.1	46.4	18.1	5.4	12.0	26.1	68.6	58.4	44.2
	100	56.0	31.3	21.8	3.9	10.2	36.4	59.9	41.4	58.3
LSD (<0.05)	Crop	NS	NS	NS	NS	NS	2.4	NS	NS	NS
	N	NS	NS	NS	NS	NS	9.0	NS	NS	NS
LSD (<0.05)	I-D/W†	NS	NS	NS	NS	7.0	7.1	NS	NS	NS
	I-D/L‡	NS	NS	NS	NS	NS	5.9	NS	NS	NS

†Wheat (Irrigated vs. Dry)
‡Lentil (Irrigated vs. Dry)

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